THE ENVIRONMENTALLY FRIENDLY COASTAL GOLF COURSE: AN ARCHITECT AND SUPERINTENDENT'S MANUAL

CHARLESTON HARBOR PROJECT
GOLF COURSE MANAGEMENT PLAN - PHASE III
FINAL REPORT

TIWET PROJECT NUMBER: 09433

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OCTOBER 1995

Preface

Golf courses are manipulated environments that provide a good quality turf surface and a challenging physiographic design. These ecosystems require significant energy to maintain their organization. Energy includes chemicals (nutrients and pesticides) as well as physical labor to mow and keep the course in order. The challenge to today's golf course architects, developers, superintendents, and managers is to facilitate the coexistence of this high-energy ecosystem with sensitive ecosystems immediately adjacent to the golf course. This is especially true along the coast where golf courses are literally designed into beach dunes and through sensitive marsh habitats. From design through construction and throughout maintenance, environmental quality must be considered. While this may appear to be a lot of trouble, the rewards are tremendous. The production of a challenging course with an excellent playing surface in an environment that is aesthetically pleasing will be enthusiastically received by golfers. Not only will they be able to enjoy the game of golf, but they will also be entertained by the wildlife that will inhabit the golf course. Ultimately, golf courses, if designed and managed properly, may become havens for endangered species whose habitats have been lost to other types of development. This document is designed to serve as a guide for the design, construction and maintenance of golf courses in the coastal Southeastern United States.

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1.0 Introduction

Golf is a multibillion dollar business that requires the alteration of large tracts of land and the use of enormous amounts of pesticides and fertilizers to maintain the well manicured course that is expected those paying to play. Over the past decade, the game of golf has experienced a tremendous increase in popularity as both a recreational and spectator sport (Lareau, 1995). The state of South Carolina, with approximately 326 golf courses, is second only to Florida as the most popular golfing destination in the country (Lareau, 1995). Each course, averaging between 124 and 180 acres (Beard, 1982; Watson, 1990) is managed by a superintendent that is educated, to some degree, in the art of turfgrass maintenance. The turfgrass industry includes not only golf courses but other sports' playing fields and home lawns. Of this huge industry, golf represents approximately 6% of the total money involved (Cockerman, 1985; Watson, 1990). Different regions of the country require specific management strategies due to differences in climate, geology, and hydrology. Therefore, superintendents have their own strategies for their course that was developed from experience and various other sources, such as the scientific literature and professional conferences. Golf course superintendents have realized the need for these management techniques to be environ-mentally friendly. James Balogh and William Walker (1992) listed potential environmental effects by golf courses. Leaching and runoff of nutrients and pesticides topped the list. Soil erosion and sediment losses during construction was also on the list. Degradation of surface waters receiving runoff may result in exposure of nontarget organisms to pesticides and elevated nutrient levels. Over-use of chemicals may expedite the development or resurgence of resistant insects and turfgrass diseases. The nature of turfgrass maintenance may result in excessive use of water resources. Development and construction may also disturb sensitive wildlife habitats such as wetlands.

2.0 Golf Course Architecture/Design

Golf courses should be designed to integrate with the natural geography of the site. This means that the golf course should compliment the natural resources of the site and, in turn, the natural resources should help make the course unique. Although no two golf courses and the associated natural resource will be identical, certain questions concerning environmental issues should be addressed during the planning, review and construction process (Love, 1992). These questions include the following:

1. Does a golf course constitute the elimination of open or green space by making use of a site which is currently undeveloped?

2. Will the proposed golf course alter or eliminate wetland and other sensitive environmental areas that may exist on the site?

3. Are there significant historical or archaeological areas on the site that will be affected by the golf course?

4. What impact will the golf course have on the ecological systems of the site, such as plant life and wildlife habitat?

5. How will the golf course affect the existing character of a site through alteration of the topography and vegetative cover?

6. Is there any potential for water pollution from earth disturbance and erosion during the construction of the golf course?

7. Will the irrigation requirements of the golf course lead to the reduction or depletion of water supplies, especially in areas experiencing conditions which limit water resources?

8. Will the long term application of chemicals for turfgrass management on a golf course cause water pollution from surface runoff or infiltration into the ground?

By addressing these issues during the planning stage, the developer can avoid deleterious environmental impacts as well as costly delays in the development process. The end result is a more successful design, development and construction project that produces an enjoyable recreational facility that is aesthetically pleasing, and environmentally compatible.

The most successful approach to insure a successful completion of the project is to form a team of experts. This team should include a golf course architect, engineer, landscape architect, water resources specialist, environmental specialist, and other consultants as dictated by the peculiarities of the golf course and the watershed in which it is sited. This team then works with the developer to determine the goals of the project: What kind of golf course will we create? It should be remembered that the geography of the proposed site will be the most important factor in determining what kind of course will be developed.

During site selection and golf course design, the team must become intimately familiar with the environmental aspects of the site. Site selection guidelines proposed by the Royal Canadian Golf Association (1993) include the following:

1. Assess the physical and economic viability of a golf course on a particular site.

2. Endeavor to select sites outside of agricultural land use zones where possible. Should agricultural land be the only option, follow local and state agricultural guidelines when selecting development sites.

3. Respect unique wetland qualities and other sensitive natural areas, avoid the disturbance of these areas and incorporate these features into the design.

4. Consider present or potential aggregate resources when determining location.

5. Ensure the project conforms with all state and local land use plans and zoning bylaws.

6. Ensure adequate water supply is available for all potable and irrigation needs of the golf facility and neighboring properties.

7. Be available to meet with the public and answer their concerns regarding the development site.

The sum total of all reconnaissance and analysis should be a series of maps illustrating existing roads and property boundaries, water sources for both irrigation and consumption, topography, sensitive wildlife habitat, potentially high erosion areas (steep slopes), wetlands and required buffer areas, drainage patterns including floodplains, vegetative cover, historical or archaeological sites, right-of-ways or easements, utilities including power and sewer, scenic views and vistas, adjacent land uses and other information critical to planning and designing the golf course. It is critical, at this point, to be intimately familiar with all rules and regulations governing the construction and management of the golf course. This will help establish realistic goals and produce the most efficient planning and design. In particular, this approach will avoid costly revisions and delays during the review, permitting and construction process.

Additional design considerations suggested by the Royal Canadian Golf Association (1993) include the following:

1. Select plant species that are best suited to the local climate and require the minimum of inputs.

2. Design the irrigation to efficiently use water only where and when needed.

3. Investigate the feasibility of alternative or supplemental sources of irrigation water, e.g., on-site storage reservoirs for storm water runoff collection or effluent. On-site retention of stormwater runoff should be considered on soils with low infiltration rates.

4. Maintain a vegetative buffer zone of at least 10 meters adjacent to all water courses to assist in filtering any nutrients or pesticides from storm run-off, and to moderate water temperatures.

5. Retain as much natural cover as possible and enhance vegetation through supplementary planting of trees, shrubs and grasses, especially along fairways, to provide wildlife habitat and along water courses supporting a fish habitat.

6. Incorporate as many natural features and areas in the design as possible to minimize disturbance of the existing ecology.

7. Consider future maintenance requirements of all golf course design features.
Low-maintenance features that require less intensive management are preferred.

A well-balanced landscape design for the golf course results in a mix of shrubs, trees, grassy areas, and water features that sustains and encourages wildlife and plant diversity. This design should balance the correction of poor drainage and erosion, with the need to maintain wetland habitats.

Wetland habitats are particularly critical not only for wildlife but also for water treatment, processing and storage. Whenever possible, golf courses should be designed such that irrigation and stormwater runoff move from the edges into the middle of the course.

Drainage ditches should be bisected by small swales or even natural or constructed wetlands. These geographic features slow down the water and allow for assimilation of both nutrients and pesticides by the vegetation. These geographic features can be picturesque playing hazards that make the course more challenging.

In many locations, water quantity and quality may be the limiting factors in golf course development. A wise water use plan might include the recapture and reuse of irrigation water as well as the use of secondary treated effluent water from a municipality or surrounding housing development for irrigation. Wetlands are extremely important for both their water-holding capacity as well as their water purification capacity. These features will increase water recapture by the golf course as well as help to alleviate fears by home owners over the use of wastewater treatment effluent on the course.

3.0 Golf Course Construction

Once the planning and design processes have been completed, the construction phase of development is initiated. The environmental issues concerning construction will have been addressed during the design of the golf course. According to Love (1992), the construction documents will vary depending upon the architect and local regulations, but typically include:

1. Staking plan to locate the key points of the golf course (tees, landing areas and greens) in the field for review and construction.

2. Erosion control and stormwater management plan to show the location of features and methods of controlling stormwater and erosion on disturbed areas of the site during construction.

3. Clearing plan to indicate the limits of clearing necessary for construction of the golf course. Specimen trees to be saved or areas of vegetation to be preserved will be shown on this plan or designated in the field.

4. Grading and drainage plan to show the overall plan for construction of the golf course and the earth work necessary to create features and produce the proper drainage.

5. Green plans to provide details for the construction of each green complex.

6. Construction details and sections to show how the features (trees, bunkers, mounding, ponds, etc.) are to be constructed in conjunction with the grading and drainage plan.

7. Irrigation plans and details to provide the information for the type of irrigation system and pump station to be installed for the golf course.

8. Grassing plan to indicate the areas where specific turfgrasses, and in some cases, ornamental grasses are to be planted on the golf course.

9. Landscape plan to serve as a guideline to show where plant material is to be installed to enhance the design of the golf course. As a part of this plan, conservation areas can be established throughout the golf course.

10. Specifications and bid documents outline the methods and details of construction for the completion of the course.

At this stage of the process the golf course superintendent should be hired. The superintendent will inspect the construction process daily and serve as the on-site representative for the owner and the architect. During the construction process, site visits are made by the golf course architect, accompanied at times by other members of the consultant team to inspect the work and see that the intended level of design and quality in the course is being accomplished. These visits facilitate the close interaction between the architect, design team and the construction team that will ultimately produce the distinctive features and character of the golf course. These visits also provide the opportunity to monitor the controls and management techniques that are in place for environmental protection.

The construction process starts with the stakeout of the golf course by a surveyor or engineer. This process is reviewed by the architect and minor field adjustments made to improve the golf course by responding to existing terrain, by integrating natural features, by providing further protection for sensitive areas and by the preservation of specific natural features such as trees, rock outcroppings and sand dunes in the design.

Soil erosion control features are then installed and checked to ensure proper placement and installation prior to the clearing and grading of the site. It is critical that these controls remain in place throughout construction and stabilization of the disturbed areas (e.g. turf establishment). Stormwater management controls are also installed very early in the construction phase to control drainage of the site and avoid impacts to sensitive areas. This is the time when natural geographic features such as ponds, grass swales and wetlands are incorporated into the water management plan.

The next step is grading the golf course. It is important to remember that the objectives during grading the course should be to avoid excessive disturbance, produce the necessary drainage contours, and provide the features required by the golf course design. An irrigation system is installed after grading has been completed. The system must be complete and operational to support the planting of the golf course. Care should be taken to design the irrigation system such that spray is directed inward onto the course and little drift off of the course occurs. This is particularly important if fertigation or chemigation is planned.

After grading and installation of the irrigation system, the course should be prepared and planted with the specific types of turf grass or ornamental grass required by the golf course design. Native species should be used to reestablish rough and areas designed to make the course more visually pleasing. The overall landscape design should include specific areas designed to promote wildlife habitat.

Additional construction considerations suggested by the Royal Canadian Golf Association (1993) include the following:

1. Protect or re-establish native groundcover and understorey species during and after construction.

2. Schedule construction to protect soils by minimizing the time ground is left without cover. Protect soils during construction through the use of mulching materials, hydro-seeding or sod.

3. Monitor ground water quality before and after construction.

4. Avoid construction near water courses, especially during fish spawning season. However, if construction is necessary, ensure adequate mitigative measures are in place to protect water quality, fisheries and stream-side habitats. Contact the local regulatory agencies for guidance.

4.0 Golf Course Management

Public concerns for the environment have led to the idea of best management practices (BMP's) for golf courses. Krivak (1978) conceptualized BMP's for agricultural crops. The BMP concept consist of five basic goals: 1) decrease the offsite transport of pesticides and nutrients, 2) control the application of these chemicals, 3) decrease the total chemical loads, 4) use both biological and mechanical soil and water conservation plans (SWCP's), and 5) educate both the managers and the public about the relationship between environmental issues and golf course management (Balogh and Walker, 1992). To date, the lack of published data has forced superintendents to rely on experience and trial and error methods for coping with some management problems. Below are management strategies that are plausible for superintendents in coastal regions of the southeast.

4.1 Water

Water is a very important component in the management of a golf course. This portion of the chapter will discuss the various uses of water on a golf course (i.e. irrigation, hazards, and aesthetics). Attention will be given to sources of water used in irrigation and subsequent management of possible runoff, as well as the management of both existing and man-made bodies of water found on the property.

4.1.1 Irrigation

Maintenance of optimal soil moisture levels is paramount in the turfgrass industry. This may pose a problem for some coastal golf course superintendents. A recent book from USGA (1994) provides an excellent guide for water conservation activities on golf courses. The following is a more general overview of the problems faced by superintendents and some possible alternatives. The combination of limited natural sources and budget constraints may hinder optimal water usage. In order to maintain the lush green carpet of turfgrass, an extremely large quantity of water is used. The first question that must be answered is, "Where will the water for irrigation come from?" The southeast has an average annual rainfall of 60-100 inches with subsequent average annual runoff of 5-20 inches (U.S. Water Resources Council, 1978). This then results in an average annual surplus of 0-20 inches of rainfall. A survey of South Carolina golf course superintendents in 1992 revealed that approximately 70% of the water used for irrigation was taken from surface water sources (i.e. lakes, ponds, streams) (Forsythe *et al*., 1993). Purchase of potable waters or secondary treated effluent consisted of less than 10% of irrigation waters used by those superintendents responding.

Lakes, ponds, and streams on the golf course may serve as an adequate source of irrigation water. However, in coastal areas the salinity of these water bodies may be detrimental to turfgrass, thus eliminating them as possible sources. Dilution of these brackish waters with potable or other freshwaters can reduce the need for purchasing water for irrigation purposes.

Purchasing potable water is another option. This may be done as a sole source or simply as a means of augmenting another supply source. In either case, this source of water can be very expensive.

The push for water conservation has resulted in the management technique of using secondary treated effluent for irrigation (Roberts and Roberts, 1989; Payne, 1987). This practice can be beneficial to all involved. Nutrient levels in the effluent will supplement the application of fertilizers, thus reducing the amount of fertilizers purchased and applied. In coastal areas in particular, the sand content of the soil also serves to filter out bacteria and other contaminants found in the effluent. This then decreases the possible chances of ground water pollution. However, the use of effluent for irrigation is strictly regulated. Of the few golf course in South Carolina utilizing effluent for irrigation, the proportion of effluent to other sources used is highly variable. It may range from 1% effluent to 100% effluent (Forsythe *et al*., 1993). The state of South Carolina currently has its own guidelines for wastewater reuse. The U.S. EPA has set forth conservative guidelines for golf courses from which states may regulate more aggressively (U.S. EPA, 1992). These guidelines include: limits on fecal coliforms, recommendations that wastewater receive secondary treatment, filtration, and disinfection, setback limits for distances between irrigated areas and potable water sources, and maintenance of minimal residual chlorine levels (USGA, 1994).

4.1.2 Lakes/Ponds/Streams

Flood control of existing water bodies and those constructed on the course is a very important issue to be addressed. Heavy rainfall may cause large runoff volumes from the golf course, which may carry high loads of nutrients and pesticides. Therefore, a superintendent must maintain all drainage structures so as to insure the proper control of excess water. In part, these aspects of management are built into the golf course at the design and construction phase. But as a golf course ages, erosion must be curbed and fouling of drains need attention. In most situations lakes and ponds on the course will be used to collect runoff and will be able to hold nearly all input. A survey of South Carolina superintendents revealed that lakes, ponds, and streams are the habitats most likely to receive golf course runoff (Forsythe *et al*., 1993). It is the runoff into creeks and streams that is of most concern. Here organisms will be exposed to various chemical as well as physical stressors. The planting of aquatic macrophytes in these areas may help slow flow and filter contaminants (See Wetlands, this chapter).

Water quality should be monitored in all bodies of water subject to the effects of golf course management. The measurements to be made are discussed in more detail in Chapter 5. The most common problem superintendents are faced with in managing water quality is fluctuations in dissolved oxygen. Decline in dissolved oxygen due to eutrophic conditions can be ameliorated firstly by controlling algal blooms that are the major contributor to oxygen consumption in early morning hours, and secondly by treating the problem directly. The addition of an aerator in ponds and lakes receiving nutrient rich runoff will help quench the extreme dissolved oxygen shifts. Assimilation of excess nutrients by wetlands is a management technique used to improve water quality that will be discussed later in this chapter.

Biological integrity of aquatic systems is the focus most of the public looks for in assessing the effective management of golf course runoff. There are the obvious effects of pesticides to be considered, but in reality, nutrient loading generally has a larger impact.

As discussed previously, algal blooms can be attributed to increased levels of nutrients. These algae form the base of an aquatic foodchain, thus they are all important to the overall system health. However, algal blooms do require management at various times of the year. Application of copper sulfate to the water is a common method employed to control the growth of algae. Typically application rates for the control of algae are below levels toxic to other aquatic organisms. This is an area of management that can be addressed at the design/construction phase of a golf course. The use of existing or constructed wetlands and riparian zones can reduce the total loading of nutrients into aquatic systems, subsequently decreasing the growth rate of algae.

Aquatic macrophytes such as duckweed, widgeon grass, and cattail can play a large role in the assimilation of chemical input to aquatic systems as well as serving to control erosion. Their growth can be controlled by various means. Mechanical means may be employed to physically remove the plants, or biological controls (i.e. grass carp) may be used. Due to the toxicity of many herbicides to aquatic organisms, there are only a few recommended techniques for their use in the control of aquatic plants.

Management of fish and invertebrates in golf course systems normally consist only of selecting species to be stocked into a lake or pond. If no additional species are to be added, the management is limited to monitoring of fish health and water quality. If public fishing is allowed, fish flesh samples should be analyzed for any harmful pesticide residues. When constructing a body of water on a golf course one should consider the ramifications of stocking it with fish. Unless it is to be utilized as a fishery, it might be worth considering limited stocking. If a lake or pond will receive golf course runoff then there is a chance of exposure to pesticides that could result in unsightly fish kills. Larger fish species are more sensitive low dissolved oxygen levels and are more conspicuous to the public. Species sensitivities to pesticides vary. Some sensitivity values can be found in Table 1 for commonly used pesticides in South Carolina.

Table 1. Species sensitivities to pesticides commonly used by South Carolina superintendents in coastal counties (excerpt from Balogh and Walker, 1992).

Chemical	Species	Effect	Concentration (ug/L)	Reference
Chlropyrifos	P. pugio	Avoidance	1.00	Hansen *et al*., 1973
	G. fasciatus	96-hr LC50	0.32	Sanders, 1972
	H azteca		0.14	Siefert, 1987
	D. magna	24-hr LC50	0.40	Roberts and Miller, 1971
	Atlantic Silverside	96-hr LC50	1.70	Schimmel *et al*., 1983
	L. macrochirus		2.40-30	"
	I. punctatus		280	Johnson and Finley, 1980
	P. promelas		120-170	Jarvinen and Tanner, 1982
Chlorpyrifos	Inland Silverside	96-hr LC50	4.20	Clark *et al*., 1985
	G. affinis		280	Carter and Graves, 1972
	F. heteroclitus		4.65	Thirugnanam and Forgash, 1977
	C. variegatus		5.40	Schimmel *et al*., 1983
Glyphosate (Rodeo)	L. macrochirus	96-hr LC50	135,000-220,000	Folmar *et al*., 1979
	I. punctatus		130,000	"
	P. promelas		97,000	"
	Rat	LD50	>5,000 ug/L	Monsanto, 1983
Gyphosate (Roundup)	D. magna	96-hr LC50	43,000	Folmar *et al*., 1979
	L. macrochirus		1,800-5,000	"
	I. punctatus		13,000	"
	P. promelas		2,300	Johnson and Finley, 1980

4.2 WETLANDS AND RIPARIAN ZONES

Geographic features such as wetlands and riparian zones are valuable natural resources. Wetlands are one of the most valuable natural resources in the United States today. They serve many purposes in nature, ranging from habitat for wildlife to a means of water quality improvement. More than half of the wetlands in the United States have been destroyed (U.S. EPA, 1988b). In the past, golf course developers, as well as other land developers, have viewed wetlands as problems from both a construction and a regulatory view. More recently, however, golf course developers, managers, and scientists are recognizing that wetlands and other geographic features may be essential to environmentally sound golf course management (Peacock et al., 1990).

4.2.1 Natural

Natural and constructed wetlands and riparian zones may be incorporated into golf course design. These features, when fully integrated into the water management strategy, act as natural filters to remove nutrients, pesticides and suspended particulates (e.g. soil, microorganisms) from runoff water. Many courses in coastal areas are blessed with an abundance of natural wetlands and riparian zones. These geographic features provide critical wildlife habitat. In turn, the wildlife as well as the wetlands significantly contributes to the aesthetics of the course itself. It seems logical to use these natural wetlands and riparian zones, and create additional wetlands upstream from the natural ones, to improve water quality before it leaves the golf course.

The key is to create an hydrologic design that begins with irrigation and rainfall, follows runoff from tees, fairways and greens, and treats this runoff with vegetative filter strips, wetlands, and riparian zones. Collection of this treated runoff into ponds and lakes may provide a much needed source of clean irrigation water for reuse on the course.

4.2.2 Constructed

Mitsch and Jorgensen (1989) define ecological engineering as "the design of human society with its natural environment for the benefit of both." This approach is exactly the one needed for golf course design. Some principles of ecological engineering suggested by Mitsch (1993) to be applied to the construction and restoration of wetlands for nonpoint source chemical runoff (such as nutrients and pesticides present on golf courses) are the following:

1. Design the system for minimum maintenance. The system of plants, animals, microbes, substrate, and water flows should be developed for self- maintenance and self-design (Odum, 1989).

2. Design a system that utilizes natural energies, such as potential energy of streams, as natural subsidies to the system.

3. Design the system with the landscape, not against it. Floods and droughts are to be expected, not feared. Outbreak of plant diseases and invasion of alien species are often symptomatic of other stresses and may indicate faulty design rather than ecosystem failure.

4. Design the system with multiple objectives, but identify at least one major objective and several secondary objectives.

5. Design the system as an ecotone. This means including a buffer strip around the site, but it also means that the wetland site itself is often a buffer system between upland and aquatic systems.

6. Give the system time. Wetlands do not become functional overnight and several years may lapse before nutrient retention or wildlife enhancement is optimal. Strategies that try to short-circuit ecological succession or over-manage are doomed to failure.

7. Design the system for function, not for form. If initial plantings and animal introductions fail but the overall function of the wetland, based on initial objectives, is intact, then the wetland has not failed. Expect the unexpected.

8. Do not over-engineer wetland design with rectangular basins, rigid structures and channels, and regular morphology. Ecological engineering recognizes that natural systems should be mimicked to accommodate biological systems (Brooks, 1989).

Wetlands can be located almost anywhere on a golf course. This utility facilitates the integration of a challenging whole design with water and chemical management. Wetlands can be incorporated into streams by adding control structures. Blocking the entire stream is a reasonable alternative only in low-order streams. This approach is usually not cost effective and is particularly vulnerable during high flow and flooding. An alternative would be to provide an alternative channel for high flow periods. This would preserve the integrity of the wetland during intense storm events and flooding.

Riparian wetlands are those adjacent to flooding streams. These wetlands receive flood waters periodically and, in natural systems, may be seen as bottomland hardwood forests.

Forested riparian zones adjacent to small creeks and drainage ditches are extremely useful for water and chemical management. For example, runoff from a plying surface may be directed via drain pipe or shallow depressions to a riparian ditch. This ditch, with a gentle to steep sloop depending on the terrain, then empties into a wetland immediately upstream from a lake or larger order stream. In considering the complete golf course hydrologic plan, the use of several small wetlands instead of few larger wetlands should be considered. There are several advantages of locating several small wetlands in the upper reaches of the golf course (but not in the streams themselves) rather than fewer larger wetlands in the lower reaches. Loucks (1989) argues that locating a greater number of low-cost wetlands in the upper reaches of a watershed rather than building fewer high-cost wetlands in the lower reaches offers a better strategy for wetlands to survive extreme events. A particularly useful design might be the construction of multiple small wetlands in the landscape to intercept small streams and drainage tiles prior to the stream. The stream itself is not diverted; the wetlands receive water, nutrients and golf course chemicals from small tributaries, swales and overland flow. In addition, drain tiles can be located such that they provide significant amounts of water to the wetlands. These tile drains are often the sources of highest concentrations of chemicals such as fertilizers.

As discussed above, multiple smaller wetlands are usually better than one or two larger wetlands. Size and shape of the wetland should be dictated by other physiographic features such as slope. Short, wide wetlands might be appropriate for intercepting diffuse overland flow in areas with gentle slopes; long, narrow wetlands might be more appropriate for ditches, swales and streams in areas with steeper slopes. In extreme cases of the latter, terraced wetlands placed into the watershed in a stair-step style are most appropriate.

4.2.3 Construction Practices

Area Requirements. The area required for the design of a wetland to treat golf course runoff is typically a function of drainage area size, flow-rate, pesticide half-life, nutrient type and chemical concentration. While the actual ratio of wetland size to drainage area has not been conclusively determined for golf courses, research in agricultural areas suggest that a one acre wetland is adequate for a 200 acre drainage area. Flow-rate, pesticide half- life, nutrient type and chemical concentration information are all necessary to determine optimum hydraulic retention time within the wetland for chemical assimilation.

Water Depth. Most wetlands function best when the water depth is less than 18 inches. Fish are extremely important in these systems, so water depth must be sufficient to allow fish to survive harsh winters. This should not be an extensive problem in the coastal Southeastern United States.

Flow Velocity and Retention Time. Most recommendations for water flow are between 0.1 and 1.0 ft/s. In addition, average hydraulic retention should be about five days. These numbers can be used to design the capacity of the wetland. Substrate. Brodie *et al*. (1988) compared topsoil, natural wetland soil, acid wetland soil, clay, mine spoil, and pea gravel as substrates in constructed wetlands. The conclusions were that substrate source did not significantly change wetland efficiency. In general, most researchers use whatever soil is nearby for the wetland substrate. Fertilizer and lime are usually added for plant growth.

Flora and Fauna. Wetland flora remove or create an environment in which bacteria cause water pollutants to precipitate or degrade. Algae, bacteria, sphagnum moss (*Sphagnum sp*.), cattails (*Typha sp*.), bulrushes (*Scirpus sp*.), and rushes (*Juncus sp*.) have been shown to remove nutrients, sulfate and pesticides. Certainly, indigenous wetland plants should also be used but the above list will serve as a start. Many of these and other wetland plants are available either locally or through companies.

Fish and invertebrates should not be overlooked. While invertebrates will most likely colonize the wetland, small fish should be stocked. Fish serve as excellent mosquito control.

4.3 TURF

A more encompassing concept than IPM is turfgrass management systems (TMS®). It combines cultural management factors for sustained productivity, course profitability, and the integrity of ecosystems on and in the vicinity of the golf course (Balogh and Walker, 1992). They list six critical components of TMS: selection of 1) turfgrass species and cultivars; 2) soil management practices; 3) clipping and cultivation practices; 4) nutrient management; 5) irrigation and drainage management; and 6) chemical, biological, and cultural pest management. The goal of a TMS approach is to balance costs, benefits, and human and environmental health with sustaining an acceptable playing surface. Computer expert systems for planning turf management such as TURFPLAN appear to work well for low maintenance applications, but fall short of designs of human experts for high maintenance turfgrass such as golf courses (Liu *et al*., 1991).

4.3.1 Fertilizers

Balogh and Walker (1992) have outlined some basic principles of nutrient management that are consistent with TMS programs. The first and most important principle is to use the minimal rates of nitrogen and phosphorus needed to maintain appropriate nutrient levels and avoid losses to runoff or leaching. Improving uptake efficacy will also minimize nutrient losses. Applications of fertilizers should coincide with the growth requirements of the specific turfgrass species. Traffic patterns and intensity should be monitored and taken into account in calculating potential for runoff. Selecting different application techniques can also reduce losses as can variations in formulations used. Related to application techniques is the necessity to have properly calibrated equipment. Some measure of quality control and quality assurance needs to be conducted in order to assess the efficacy of the nutrient management plan.

Fertilizer management poses some concerns similar to those associated with pesticides. Petrovic (1990) summarizes and reviews the literature dealing with nitrogenous fertilizer usage. Nitrate (NO_3) originating from cess pools, septic tanks, animal and human wastes, and fertilizers (Keeney, 1986) is one of the most widespread groundwater contaminants (Pye *et al*., 1983). Nitrogen and potassium fertilization of turfgrass has been linked to resistance to stress conditions brought on by disease, drought, or human foot traffic (Beard, 1973; Cook *et al*., 1983; Markland, 1969).

The distribution of nitrogenous fertilizers is normally studied as a series of components rather than a complete system. Even though conclusions are limited to a certain cultural and geological situation, Starr and DeRoo (1981) attempted to study all of the components. Atmospheric loss of nitrogen may occur via NH_3 vaporization or denitrification. Ammonia volatilization can be decreased by irrigation (Bowman *et al*., 1987), decreased thatch content, and the use of time-release nitrogen pellets (Nelson *et al*., 1980). The process of denitrification and its effects are limited in the literature (Mancino *et al*., 1988).

Controlled-release or time-release fertilizers are used commonly on turfgrass (Turgeon, 1985). A study of reactive layer coated (RLC) nitrogen (Peacock and DiPaola, 1992) yielded results indicating that their effectiveness depends upon the thickness of the reactive layer coating. A similar study involving controlled-release potassium (Snyder and Cisar, 1992) looked at the coating material's effect on potassium release. Sulfur-coated (SC) released potassium too rapidly, while the converse was true for resin-coated (RC) potassium. All other sources of potassium had favorable characteristics.

4.3.2 Pesticides

Probably foremost in the mind of a superintendent when planning pesticide management is the safety of the workers and golfers. A few studies have made attempts at finding safe levels of dislodgeable residues and the time required post-application to achieve them (Goh *et al*., 1986; Harris and Soloman, 1992). The results indicate that for most pesticides used, there is little risk involved with reentry to a treated site. A method for quantifying airborne loss of pesticides was described by Jenkins *et al*. (1991). Pest control involves the use of a wide range of chemicals including insecticides, herbicides, nematicides, and fungicides. Plant growth regulators (PGRs) may also fall into this category because of the basic chemical makeup. Continuous use of pesticides in turfgrass management strategies may also lead to an increased resistance by the target organism (Potter and Braman, 1991). Outside of pure turf management concerns, the superintendent must also be environmentally sensitive and be concerned about pesticide runoff. Binding to thatch, which increases retention time for degradation processes, is reported to diminish the amounts of pesticides in runoff to safe levels in receiving waters (Miles *et al*., 1992; Potter and Braman, 1991; Watschke, 1990).

The only practical method for preventing serious damage of turf by insects is the use of **insecticides** (Potter and Braman, 1991). Insecticides may have indirect effects that counteract or cause a more serious problem. They have been shown to adversely affect earthworms, causing thatch buildup (Randell *et al*., 1972). Populations of predators and parasitoids in the soil may also be diminished causing some secondary outbreak (Cockfield, 1983). Conservation of these natural enemies should factor into pesticide selection.

Certain commonly used **herbicides** also pose the threat of causing phytotoxicity and decreased turf quality. The timing of applications to sensitive turf species such as creeping bentgrass is very important (Shim and Johnson, 1992).

Frequent use of select **fungicides** may enhance some nontarget diseases, while the nontarget benefits appear to be turf species dependent (Dernoenden and McIntosh, 1991). Dollar spot, a common disease found on golf courses (Smiley, 1983) was effectively suppressed with applications of compost (Nelson and Craft, 1992). This research was based on the fact that composted substrates hold disease-suppressive properties due to their microbial content (Hoitink and Fahy, 1986).

The use of plant growth regulators for golf course applications are limited due to the potential for turf damage and inconsistent results (Christians, 1985). Some **PGRs** have been found effective if used in areas that are hazardous for trimming or mower operation (Fry, 1991). Fry also reported that Glyphosate (0.6 kg/ha) caused unacceptable phytotoxicity. Johnson (1992) reported variations in effects, from slight to moderate turf damage by two PGRs.

Recovery was complete by 10 weeks. This would appear unacceptable for the golf industry that is forced to maintain turf at the highest quality possible.

An alternative to the use of pesticides that has some promise is that of biological pest controls (Meyers *et al*., 1992). Cranshaw and Zimmerman (1989) reported effective results when using nematodes to control turfgrass scarabs. They also go on to point out problems associated with this practice, such as: availability, storage, cost, handling, and reliability.

4.3.3 Control of other pests

Other pest such as raccoons, deer, geese and other birds should be controlled according to local regulations. Trapping or harvesting humanely may be effective. Care should be taken when handling wild animals as they are vectors for various diseases, such as rabies.

5.0 GOLF COURSE ENVIRONMENTAL MONITORING

Equally as important as a sound management strategy; a well planned monitoring program will ensure the integrity of the environment, while assessing the efficacy of the management techniques. Obviously, there is concern for possible negative impacts on nontarget organisms by chemical management strategies (Kendall *et al*., 1992; Stone *et al*., 1985a and 1985b; and Stone, 1979). Less than 10% of South Carolina superintendents responding to a survey (Forsythe *et al*., (1993) reported to have had a fish or wildlife kill on their golf course during the first five months of 1992. However, detrimental effects may go unnoticed to those lacking the appropriate training and using a poorly designed monitoring program. A monitoring program should be designed to include both aquatic and terrestrial systems. Monitoring techniques range from simple, low-cost, on-site methods done by golf course personnel to stringent, expensive tests conducted at contract laboratories. The overall plan should include techniques that span this entire range. Observations of wildlife and basic water quality measurements can easily be conducted during normal maintenance routines. Environmental samples can also be collected and shipped to a laboratory for nutrient and pesticide analyses. However, these data alone cannot effectively assess the management plans. Computer simulation models can be used to assess current management techniques and those to be used in the future (Balogh and Walker, 1992). An extensive discussion of available models and their applications can be found in Balogh and Walker (1992). Below is a compilation of monitoring techniques that might be used by golf course superintendents. Some methods are necessary, some strongly recommended, while others are options to superintendents with a larger budget.

5.1 AQUATIC

Balogh and Walker (1992) have outlined the potential detriments of construction and management of golf courses. Probably the most important concern of the present is the potential for contamination of surface and groundwaters with sediment, nutrients, and pesticides (Cooper, 1987; Grant, 1987; Klein, 1990; U.S. EPA, 1986 and 1988a; Keeney, 1986;

Petrovic, 1990; Pratt, 1985; and Pye *et al.*, 1983). Wetlands, ponds or lakes, and riverine systems were the type of habitat receiving the runoff from 21, 67, and 40% respectively, of the South Carolina golf courses surveyed in 1992 (Forsythe *et al.*, 1993).

5.1.1 General Water Quality

Monitoring general water quality parameters greatly enhance a superintendent's management strategies. Water quality parameters such as pH, dissolved oxygen, and temperature can be very useful in assessing any problems associated with golf course management. Other parameters that may also be of consequence include hardness, alkalinity, and salinity. All of these are possible factors in the fate and effects of chemicals in the aquatic environment. Each will be discussed below in light of why, how, when, and where to monitor these general water quality parameters. All can be done by golf course personnel with limited training and equipment needs.

Both direct and indirect effects can stem from altered **pH** levels. Outside the normal pH range of aquatic systems, 5-9, direct effects are graded (Rand and Petrocelli, 1985). Indirectly, pH can affect the hydrolysis of organophosphate insecticides. This then controls the levels of pesticide available to aquatic organisms. One should monitor pH with an independent pH meter daily in all water bodies on the course. If funds permit, a HydroLab® meter can be used to monitor pH as well as many of the other parameters simultaneously. This decreases measurement time and allows for the data to be down-loaded to a computer for long-term record.

Dissolved oxygen (DO) is possibly one of the most important water quality parameters to be monitored. This is the source of oxygen for all aquatic organisms and its availability can have profound ramifications on the system. The effects of DO fluctuations in a system can be severe. Dissolved oxygen changes on a regular diurnal pattern. As evening approaches, level are highest due to the photosynthesis of algae during the day. Just before sunrise the consumption of oxygen by all organisms is at its maximum and thus the DO levels are the lowest. This is a naturally occurring situation that alone may cause fish kills. Therefore, DO should be monitored twice daily (i.e. morning and evening) everyday. This allows for the distinction between natural DO effects and any possible pesticide effect. Another item to note is that if a fish kill has occurred, normally larger fish are affected most by low DO levels and smaller fish affected most by pesticide contamination. Again individual meters are available, but a combination meter is desired.

Temperature is a factor that typically has few direct effects seen in a golf course ecosystem. Indirect effects on DO and organismal metabolism are its main routes of influence. The ability of oxygen to remain dissolved in water is inversely proportional to the water temperature. Thus, as the water temperature rises the dissolved oxygen will decrease. Increases in temperature also cause an increase in metabolic rate and ventilation of aquatic organisms. Reports are conflicting as to whether this causes increased toxicity of pesticides. Increased ventilation results in an increase in uptake of dissolved toxicants but the concurrent increased metabolism may also enhance the enzymatic breakdown of contaminants. Surface water temperature should be recorded daily in all bodies of water.

Hardness is defined as the concentration of all metallic cations, except those of the alkali metals (Rand and Petrocelli, 1985). In practice it is the measurement of the concentration of calcium and magnesium ions in water, usually expressed as mg/L calcium carbonate equivalent. Hardness has been shown to have little effect on organophosphate toxicity (Pickering *et al*., 1962). Its effects are more commonly seen in relation to metal toxicity. Since metals are typically not a golf course related problem, the measurement of hardness is just a measure used to assess changes in water quality. Hardness is determined by a titration method (ASTM, 199?). An indicator solution and buffer are added to the water sample, followed by titration with 0.01 M EDTA. Water samples (100 mL) for hardness analyses should be acidified with nitric acid (HNO_3) and stored no longer than 6 months. Hardness should be measured monthly in all water bodies, or immediately following any fish kills.

Alkalinity is defined as the acid-neutralizing capacity of water. It is measured as the combination of carbonate and bicarbonate present in the water. Therefore, it has a close relationship with pH. Increased alkalinity values will stabilize pH. Estuarine and marine waters are less susceptible to pH variation due to the high concentrations of carbonate and bicarbonate naturally present. Freshwaters of the southeast typically have low alkalinity values and are subject to wide pH changes (Novotny and Olem, 1994). The measurement of alkalinity is somewhat more tedious. A water sample must be titrated with sulfuric acid (0.02 N H_2SO_4) after the addition of an indicator solution (ASTM, 199?). Water quality test kits are commercially available for this method. Water samples (200 mL) for alkalinity analyses should be refrigerated and stored no longer than 24 hours. Alkalinity should be measured monthly in all water bodies, or immediately following any fish kills.

Salinity is a factor that may be important for coastal golf courses. A few studies have shown the role salinity plays in pesticide toxicity. The mosquitofish, *Gambusia*, exhibited decreased accumulation of organic pesticides with increased salinity.

5.1.2 Pesticide and Fertilizer Residues

Evaluating the cause of a suspected chemical induced "fish kill" typically requires that a minimum number of water samples be collected. The final assessment can only be as good as the sample integrity. It is all important that samples be collected correctly, identified uniquely, and preserved in accordance with accepted methodologies. The samples must then be shipped and tracked properly. A logbook is critical in the identification of and tracking of samples. The location, date, and collectors initials also need to be recorded. The following will outline some accepted methodologies for sample collection and shipment, as well as provide an estimate of the costs involved in analyses.

5.1.2.1 Water

Following a "fish kill," and analyses of general water quality have been conducted samples from both affected water bodies and those appearing normal should be taken. Samples of groundwater from monitoring wells should also be taken periodically (i.e. according to local regulations). The number of groundwater wells will depend upon the potential for contamination of offsite aquifers. Surface-water may be sampled periodically for nutrient loading, but is usually only sampled for pesticides following an episode of mortality.

The samples should be placed in clean containers and stored according accepted methods. Pesticide samples (1000 mL) should be placed in amber glass bottles and capped with a teflon-lined lid. The bottles need to be rinsed with organic solvents prior to use, and re-rinsed with water from which the sample is being taken. All samples should be kept at 4 C and in darkness. It is recommended that analyses be conducted within 7 days. The cost of analyses varies depending upon the procedure and number of samples. It may range from $10 to $450 and be doubled if expedited service is requested (Meyer and Barclay, 1990).

Water samples (200 mL) for nutrient analyses (nitrate, nitrite, sulfate, and phosphate) can be placed into either glass or plastic containers. Nitrate samples need to be acidified to pH <2 and refrigerated. They have a shelf-life of 48 hours. Nitrite should be analyzed immediately or frozen at -20 C. Phosphate needs to be filtered immediately and frozen at -10 C. Samples need to analyzed in the first 48 hours following collection. Sulfate samples can simply be refrigerated at 4 C and analyzed within 28 days. The cost of analyses range from $5 to $50 for these inorganics.

5.1.2.2 Biological Tissues

Discussion of collecting and shipping biological samples to appropriate laboratories is covered in each of following sections.

5.1.3 Fish

Monitoring of fish populations on a golf course may range from simple observations to full-scale toxicity tests. It is typically sufficient to minimize activities until a fish kill accrues. At that point there are several important steps to be followed so as to increase the efficiency of finding the causative agent (Meyer and Barclay, 1990). Immediately following the discovery of a fish kill, the following information must be compiled:

1) date and time of day,
2) location,
3) estimated time kill began,
4) water quality characteristics:
    a. dissolved oxygen
    b. pH
    c. water temperature
    d. color of the water
    e. odor of the water
    f. salinity
5) condition of fish seen: live, moribund, dead, or decaying,
6) condition of other organisms in the area,
7) weather conditions of the day and previous day and night,
8) physical appearance of fish: gills flared, mouth agape, spinal curvature, excessive mucus, lesions,
9) any other unusual characteristics, behavior, discolored vegetation.

Meyer and Barclay (1990) also provide a table of physical signs associated with fish mortality and their possible causes.

These observational records may be supplemented with more sensitive evaluations. If water quality is suspect, then effluent toxicity testing by a laboratory may be used to quantify toxicity. This is further supplemented by knowledge of organism exposure. Tissue screening for pesticide residues can be conducted. A more elaborate and chemical specific indicator of pesticide exposure (i.e. organophosphates and carbamates) is the level of blood and brain cholinesterase, an enzyme responsible for normal nervous system function. These monitoring techniques require extensive training and should be done by reputable laboratories.

Tissue samples for pesticide residue analyses should be kept frozen at -20 C until analysis. Composite samples should be made-up of at least three fish from each species affected and those from reference sites. Three samples should be taken for each species, from each site (Meyer and Barclay, 1990).

Table 2. Physical signs associated with fish mortality (modified from Meyer and Barclay, 1990)

	Cause of Mortality		
Physical Signs of Fish	Oxygen Depletion	Toxic Algal Bloom	Pesticide Toxicity
Fish Behavior	Gasping and swimming at surface	Convulsive, erratic swimming, lethargy	Convulsive, erratic swimming; if organophosphate pesticide, pectoral fins extended anteriorly
Species Selectivity	None if depletion is total	None, all species affected	Usually one species killed before others, depending on fish sensitivity and pesticide levels
Size of Fish	Large fish killed first, eventually may kill all sizes and species	Small fish killed first, eventually all sizes	Small fish killed first, eventually may kill all sizes
Time of Fish Kill	Night or early morning hours	Only hours of bright sunlight	Any hour, day or night
Dissolved Oxygen	Less than 2 mg/L, usually less than 1 mg/L	Very high, often saturated or super-saturated near surface	Normal range
Water pH	6.0-7.5	9.5 and above	7.5-9.0
Water Color	Brown, gray or black	Dark green, brown, or golden, sometimes with musty odor	Normal color and little odor

5.1.4 Invertebrates

Aquatic invertebrates can serve as sensitive indicators of diffuse pollution. In order to assess most of the invertebrate health indices a collection of background data or data from reference sites not exposed to golf course management needs to be obtained. A hierarchical approach to monitoring can be taken, individual/species population level effects (e.g. effluent toxicity testing, tissue analysis, biomarkers, growth rates, etc.) or community/ecosystem effects can be investigated (e.g. species richness, relative abundance, indicator species, abundance of opportunists, dominant species, etc.)(Hoffman *et al.*, 1995). Most of these measures can be done with limited training and experience. The collection and treatment of water samples for effluent toxicity tests are as previously described in the section addressing water monitoring. If there is sufficient abundance, especially if mussels are present, tissue samples should be taken in association with fish and water samples. Samples should be placed in clean containers and frozen until analysis.

5.2 TERRESTRIAL (Techniques for Monitoring Pesticide Exposure to Birds and other Wildlife on Golf Courses)

In order to maintain quality playing surfaces, golf course managers have for years employed the use of agrochemicals, primarily insecticides and herbicides, for controlling turfgrass pests. Because golf courses often provide excellent habitat for wildlife, some insecticide applications have resulted in exposure and adverse effects to non-target animals. In recent years, however, efforts have been made by regulators, golf course managers, and environmental scientists to minimize or prevent pesticide exposure to non-target wildlife. This section of the manual will focus on techniques available for monitoring wildlife exposure to pesticides on golf courses. Emphasis will be placed on methods for evaluating exposure of birds to insecticides because the majority of documented wildlife exposures to pesticides on golf courses have involved these particular animals and compounds. However, many of the techniques mentioned can be used for monitoring other wildlife species as well.

5.2.1 Exposure of Birds to Pesticides on Golf Courses

Over the past several years, organophosphorus (OP) and carbamate (CA) pesticides have essentially replaced organochlorine (OC) compounds for the control of agricultural and turfgrass pests. This shift in chemical use is due primarily to the fact that OPs and CAs exhibit a relatively short persistence in the environment and a low potential for accumulation in the food chain as compared to OCs (Smith, 1987). However, OPs and CAs can be acutely toxic to birds (Hudson et al., 1984), and use of these compounds on golf courses resulted in numerous bird kills in the 1970s and 1980s (Zinkl et al., 1978; Stone, 1979; Stone and Knoch, 1982; Stone and Gradoni, 1985a; Stone and Gradoni, 1985b; Littrell, 1986; Stone and Gradoni, 1986; Frank et al., 1991; Kendall et al., 1992). The majority of these bird kills were related to the OP diazinon, which was subsequently eliminated for use on golf courses in 1988 (U.S. EPA, 1988). Exposure of birds to OPs and CAs may also result in sublethal effects such as decreased predator avoidance (Buerger et al., 1991; Galindo et al., 1985; Hunt et al., 1992), decreased attentiveness to nests and young (Grue et al., 1982; White et al., 1983; Brewer et al., 1988a), and adverse physiological responses (Rattner and Franson, 1984). No large-scale bird mortalities on golf courses have been reported since the cancellation of diazinon, but the potential for wildlife exposure to other OPs and to CAs remains.

OPs and CAs are anticholinesterase compounds. That is, they act by inhibiting the enzyme cholinesterase. Cholinesterase inhibition results in the accumulation of acetylcholine at nerve synapses which in turn disrupts the normal transmission of nerve impulses. Symptoms of severe OP or CA poisoning include respiratory difficulty leading to respiratory arrest, paralysis, convulsions, coma, and death (Ecobichon, 1991). Other signs of anticholinesterase poisoning in birds include pupil constriction, excessive salivation, defecation, tremors, shortness of breathing accompanied by rapid pants, and ataxia (inability to coordinate voluntary muscular movements).

The hazard presented by pesticides to wildlife on golf courses is a function of the toxicity of the compound applied and the exposure of an animal to that compound. Pesticide exposure may be determined by several factors including where the compound is applied in relation to wildlife habitat, how much is applied at a given time, how long the pesticide or its breakdown products persist in the environment, and the potential for the compound to accumulate in the food chain (Smith, 1987). These factors, along with the behavior and food habits of a species, will determine the response of the individuals exposed. For example, some species of waterfowl (American wigeon, Canada geese, etc.) feed on grass while other species such as blackbirds and thrushes feed on seeds, grit, and invertebrates found in the thatch layer and soil surface. Following a chemical application, the waterfowl may be exposed orally through direct ingestion of pesticide in treated turfgrass (Kendall et al., 1992) while the blackbirds and thrushes may be exposed through ingestion of contaminated insects (Stickel, 1974; Brewer et al., 1988b) or pesticide-impregnated granules (Balcomb et al., 1984a;

1984b). Pesticide exposure may also occur through ingestion of contaminated water in puddles resulting from irrigation or runoff (Stone and Gradoni, 1985; Brewer et al., 1993; Kendall et al., 1993). In addition to ingestion, birds may also be exposed to pesticides dermally. Direct contact with pesticide spray, treated turf, or contaminated water may result in absorption of the compound through the skin and eyes (Driver et al., 1991). Direct contact with pesticide spray may also lead to exposure through inhalation (Weeks, et al., 1977; Driver et al., 1991).

5.2.1.1 Techniques for Monitoring Pesticide Exposure to Birds on Golf Courses

Although numerous bird kills have been associated with pesticide use on golf courses, few field studies have been conducted to closely examine the hazard presented by these compounds to free-ranging birds under routine, day to day golf course management practices. Some of the field studies that have been conducted (Brewer *et al*., 1988b; Rainwater et al., 1995), however, have shown the potential for exposure of birds to certain insecticides, but few actual exposures and effects and no pesticide-related mortalities have been observed. Although these results are encouraging, it is important to note that valid extrapolation of pesticide impacts on birds from one golf course to another is difficult. Exposure and response of birds to turfgrass applications will depend on several factors including geographic location of the course, climatology and weather patterns, time of year, time of day, bird species present, and chemical use patterns. Because these factors differ among courses, each golf course can be considered unique. Thus it is important that each golf course manager be aware of the risks presented to birds and other wildlife by the different pesticides he or she chooses to apply. In addition, the manager should also be aware of bird utilization of the course, particularly those areas that will receive chemical treatment. Knowing when and where birds utilize golf course habitat will enable the manager to make pesticide applications that maximize the effects on the pest but minimize the effects on non-target species.

Several techniques are employed by researchers to monitor exposure and response of birds to pesticides on golf courses. To evaluate the potential for exposure, bird surveys and censuses are often conducted (Brewer *et al*., 1988b; Moul and Elliott, 1992). These counting techniques aid in identifying bird species at risk of chemical exposure by providing useful indices such as species richness, density, relative abundance, and relative frequency. More importantly, information on habitat use (turf, trees, shrubs, etc) and activity patterns (feeding, resting, reproduction, etc.) can be obtained which will more clearly identify the species at risk and their exposure potential.

Environmental chemistry is also a valuable tool for examining exposure potential. Various matrices including soil, water, plants, and insects are sampled before and after pesticide applications and analyzed for chemical residues. Any bird carcasses found on or near a golf course can be collected and analyzed for chemical residues as well. Results of these analyses can help pinpoint where on the golf course exposure is likely to occur, how much chemical may be available to birds, and the most probable routes of exposure.

Determining or quantifying actual exposure of birds to pesticides requires the collection of various samples from the birds themselves. With the increasing concern for animal rights issues, non-lethal sampling techniques are most often employed. These methods allow pertinent samples to be collected while preventing removal of animals from the study population. Birds may be captured using various traps or nets (Bookhout, 1994), sampled, and released (Rainwater *et al*., 1995). Samples collected from live birds to measure pesticide exposure include feather washes, foot washes, fecal-urates samples, and blood samples. Feather and foot washes are collected by rinsing a bird’s feathers or feet with a specific solvent which is collected through a funnel into a chemically clean jar and then analyzed for pesticide residues. Fecal-urate (excreta of birds; mixture of feces and urine) samples are also analyzed for pesticides and their breakdown products. Blood samples can be analyzed for both chemical residues and biochemical endpoints such as cholinesterase (the enzyme inhibited by OPs and CAs) activity. The efficacy and limitations of cholinesterase activity as an indicator of exposure and response to anticholinesterase pesticides in birds is described in detail by Hill and Fleming (1982).

Other techniques that can be used to examine exposure of birds to pesticides on golf courses include nest box monitoring and radio telemetry. Nest boxes have been successfully employed in field studies to evaluate the effects of environmental contaminants on birds (Grue *et al*., 1982; Akins *et al*., 1993). Designed to attract a particular bird species of interest, nest boxes can be placed on a golf course to promote nesting. If a colony of nesting birds is established, it can be monitored throughout the breeding season. Reproductive endpoints (number of eggs laid, hatching success, nestling survival, etc.) and dietary endpoints (pesticide residues in food items) can be examined, and blood and fecal-urate samples can be collected from nestlings. Findings can then be compared to the same endpoints monitored in birds from reference or control sites that do not receive pesticide applications.

The use of radio telemetry is also effective in monitoring birds on golf courses. Birds are equipped with radio transmitters, which allow researchers to track individuals, monitor their movement patterns, and assess their behavior and survival. Telemetry studies can also be useful in determining the possibility of off-site exposures (exposure of birds to compounds in areas other than the golf course) and in detecting and locating dead birds.

5.2.2 Wildlife in General

In discussing exposure of birds and other wildlife to pesticides on golf courses, it is important to note that not all exposures necessarily have adverse effects. Low levels of exposure have been observed in birds on golf courses with no obvious mortality or other negative effects (Brewer *et al*., 1988b; Kendall *et al*., 1993). Nonetheless, it is still important that golf course managers be aware of the wildlife species that frequent their courses and the risks incurred upon them by pesticide applications. It should be realized that merely following the label rate does not ensure that wildlife will not be adversely affected (Smith, 1987). Prior to a pesticide application, environmental conditions, wildlife utilization of the target area, and the benefits of chemical use versus potential adverse effects should be carefully evaluated (Smith, 1987). The timing of the application should be planned to avoid those times when wildlife are present and active on the area to be treated. Following an application, golf course managers and their staff may observe effects on wildlife, from birds exhibiting symptoms of anticholinesterase poisoning (described earlier) to die-offs. Such findings can be reported to the local extension service, state agencies, or the U.S. Fish and Wildlife Service. Reporting exposure incidents can provide valuable information as to the use conditions under which the exposure occurred which in turn will aid in determining whether the effects are the result of appropriate use or misuse of the product (Brewer *et al*., 1993).

A variety of techniques is available for monitoring wildlife exposure to pesticides on golf courses. The techniques described here pertain primarily to birds because the majority of wildlife die-offs on golf courses and related studies have involved birds. However, some of the methods mentioned or variations of them can be used to monitor pesticide exposure in other species such as mammals, reptiles, and amphibians. An awareness of the potential for wildlife exposure to pesticides on golf courses will assist course managers in developing strategies that will maximize the economic benefits of pesticide use while minimizing adverse effects on non-target animals.

References

Akins, J.M., M.J. Hooper, H. Miller, and J.S. Woods. 1993. Porphyrin profiles in the nestling European starling (Sturnus vulgaris): a potential biomarker of field contaminant exposure. J. Toxicol. Environ. Health. 40:47-59.

ASTM. 1985. Standard Methods.

Balcomb, R., C.A. Bowen II, D. Wright and M. Law. 1984a. Effects on wildlife of at-planting corn applications of granular carbofuran. J. Wildl. Manage. 48:1353-1359.

Balcomb, R., R. Stevens and C. Bowen II. 1984b. Toxicity of 16 granular insecticides to wild-caught songbirds. Bull. Environ. Contam. Toxicol. 33:302-307.

Balogh, J.C. and W.J. Walker. 1992. Golf Course Management and Construction: Environmental Issues. Lewis Publishers, Ann Arbor, MI, USA, 951 pp.

Beard, J.B.. 1982. Turf Management for Golf Courses. Macmillan Publishing Co., New York, 642 pp.

Beard, J.B.. 1983. Turfgrass Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, NJ, 658 pp.

Bookhout, T.A., ed. 1994. Research and Management Techniques for Wildlife and Habitats. 5th edition. Allen Press, Inc. Lawrence, Kansas. 740 pp.

Bowman, D.C., J.L. Paul, W.B. Davis, and S.H. Nelson. 1987. Reducing ammonia volatilization from Kentucky bluegrass turf by irrigation. Hort. Sci. 22: 84-87.

Brewer, L.W., C.J. Driver, R.J. Kendall, C. Zenier and T.E. Lacher, Jr. 1988a. Effects of methyl parathion in ducks and duck broods. Environ. Toxicol. Chem. 7:375-379.

Brewer, L.W., C.J. Driver, R.J. Kendall, T.E. Lacher, J.C. Galindo and G.W. Dickson. 1988b. Avian response to a turf application of Triumph® 4E. Environ. Toxicol. Chem. 7:391-401.

Brewer, L.W., R.A. Hummel and R.J. Kendall. 1993. Avian response to organophosphorus pesticides applied to turf. In K.D. Racke and A.R. Leslie, eds., Pesticides in Urban Environments: Fate and Significance. American Chemical Society, Washington D.C., pp. 320-330.

Brodie, G. A., D. A. Hammer, and D. A. Tomljanovich. 1988. An evaluation of substrate types in constructed wetlands acid drainage treatment systems, IC9183 Mine Drainage and Surface Mine Reclamation. Vol.I: Mine Water and Mine Waste, Bureau of Mines, United States Department of Interior, 325.

Brooks, R. P. 1989. Wetland and waterbody resoration and creation associated with mining. pp. 529-548. In: J. A. Kusler and M. E. Kentula (eds.), Wetland Creation And Restoration: The Status of the Science. Island Press, Washington, DC.

Buerger, T.T., R.J. Kendall, B.S. Mueller, T. DeVos and B.A. Williams. 1991. Effects of methyl parathion on northern bobwhite survivability. Environ. Toxicol. Chem. 10:527-532.

Carter, F.L. and J.B. Graves. 1972. Measuring effects of insecticides on aquatic animals. Louisanna Agriculture 16(2): 14-15.

Christians, N.E.. 1985. Response of Kentucky bluegrass to four growth retardants. J. Am. Soc. Hort. Sci. 110: 765-769.

Clark, J.R., J.M. Patrick, Jr., D.P. Middaugh, and J.C. Moore. 1985. Relative sensitivity of six estuarine fishes to carbophenothion, chlorpyrifos, and fenvalerate. Ecotoxicology and Environmental Safety 10(3): 382-390.

Cockfield, S.D. and D.A. Potter. 1983. Short-term effects of insecticidal applications of predaceous arthropods and oribatid mites in Kentucky bluegrass turf. Environ. Entomol. 12: 1260-1264.

Cockerham, S.T. and V.A. Gibeault. 1985. The size, scope, and importance of the turfgrass industry. In: Gilbeault, V.A. and S.T. Cockerham (Eds.), Turfgrass Water Conservation. University of California, Riverside, Division of Agriculture and Natural Resources, pp. 7-12.

Cook, R.J. and K.F. Baker. 1983. The Nature and Practice of Biological Control of Plant Pathogens. American Phytopathological Society, St. Paul, MN.

Cooper, R.J.. 1987. Turfgrass pesticide risk in perspective. Golf Course Management 55(11): 50-60.

Cranshaw, W.S. and R.J. Zimmerman. 1989. Biological, mechanical, and chemical control of turfgrass-infesting scarabs in Colorado. Southwestern Entomologist 14(4): 351-355.

Driver, C.J., M.W. Ligotke, P. Van Voris, B.D. McVeety, B.J. Greenspan and D.B. Drown. 1991. Routes of uptake and their relative contribution to the toxicologic response of northern bobwhite (Colinus virginianus) to an organophosphate insecticide. Environ. Toxicol. Chem. 10:21-33.

Dernoeden, P.H. and M.S. McIntosh. 1991. Seasonal quality responses of perennial ryegrass as influenced by fungicides. Hortscience 26(9): 1181-1183.

Ecobichon, D.J. 1991. Toxic Effects of Pesticides. In Amdur, M.O., J. Doull, and C.D. Klaassen, eds. Casarett and Doull's Toxicology: The Basic Science of Poisions. 4th ed. Pergamon Press, New York. pp. 580-592.

Folmar, L.C., H.O. Sanders, and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to and aquatic invertebrates. Archives of Environmental Contamination and Toxicology 8(3): 269-278.

Forsythe, B.L., L.C. Miller, and S.J. Klaine. 1993. Management practices of South Carolina golf courses: a survey of superintendents. Technical Report.

Frank, R., P. Mineau, H.E. Braun, I.K. Barker, S.W. Kennedy and S. Trudeau. 1991. Deaths of Canada geese following spraying of turf with diazinon. Bull. Environ. Contam. Toxicol. 46:852-858.

Fry, J.D.. 1991. Centipedegrass response to plant growth regulators. Hortscience 26(1): 40-42.

Galindo, J.C., R.J. Kendall, C.J. Driver and T.E. Lacher, Jr. 1985. The effect of methyl parathion on susceptibility of bobwhite quail (Colinus virginanus) to domestic cat predation. Behav. Neural Biol. 43:21-36.

Goh, K.S., S. Edmiston, K.T. Maddy, D.D. Meinders, and S. Margetich. 1986. Dissipation of dislodgeable foliar residue of Chlorpyrifos and Dichlorvos on turf. Bull. Envion. Contam. Toxicol. 37(1): 27-33.

Grant, Z.. 1987. One aspect of government relations: groundwater issues in pesticide regulation. Golf Course Management 55(6): 14-20.

Grue, C.E., G.V.N. Powell and M.J. McChesney 1982. Care of nestlings by wild female starlings exposed to an organophosphate pesticide. J. Appl. Ecol. 19:327-335.

Hansen, D.J., S.C. Schimmel, and J.M. Keltner, Jr.. 1973. Avoidance of pesticides by grass shrimp (*Palaemonetes pugio*). Bulletin of Environmental Contamination and Toxicology 9(3): 129-133.

Harris, S.A. and K.R. Soloman. 1992. Human exposure to 2,4-D following controlled activities on recently sprayed turf. J. Eniron. Sci. Health (Part B): pesticides, food contaminants, and agricultural wastes. 27(1): 9-22.

Hill, E.F. and W.J. Fleming. 1982. Anticholinesterase poisoning of birds: Field monitoring and diagnosis of acute poisoning. Environ. Toxicol. Chem. 1:27-38.

Hoffman, D.J., B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr.. 1995. Handbook of Ecotoxicology. Lewis Publishers, Boca Raton, FL, USA, pp. 755.

Hoitink, H.A.J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with compost. Ann. Rev. Phytopath. 24: 93-114.

Hudson, R.H., R.K. Tucker and M.A. Haegele. 1984. Handbook of toxicity of pesticides to wildlife. U.S. Fish Wildl. Serv. Publ. 153. pp. 7-86.

Hunt, K.A., D.M. Bird, P. Mineau and L. Shutt. 1992. Selective predation of organophosphate-exposed prey by American kestrels. Anim. Behav. 43:971-976.

Jarvinen, A.W. and D.K. Tanner. 1982. Toxicity of selected controlled release and correspond-ing unformulated technical grade pesticides to the fathead minnow *Pimephales promelas*. Environmental Pollution Serial A 27(3): 179-195.

Jenkins, J.J., R.J. Cooper, and A.S. Curtis. 1991. Field chamber technique for measuring Pendimethalin airborne loss from turfgrass. Bull. Environ. Contam. Toxicol. 47(4): 594-601.

Johnson, B.J.. 1992. Response of Tifway Bermudagrass to rate and frequency of Flurprimidol and Paclobutrazol application. Hortscience 27(3): 230-233.

Johnson, W.W. and M.T. Finley. 1980. Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates. Resource Publication 137. Fish and Wildlife Service, U.S. Dept. of Interior, Washington, D.C., 98 pp.

Keeney, D.R.. 1986. Sources of nitrate to groundwater. CRC Critical Reviews of Environmental Control 16: 257-304.

Kendall, R.J., L.W. Brewer, R.R. Hitchcock, and J.R. Mayer. 1992. American wigeon mortality associated with turf application of Diazinon AG500. Journal of Wildlife Diseases 28(2): 263-267.

Kendall, R.J., L.W. Brewer and R.R. Hitchcock. 1993. Response of Canada geese to a turf application of diazinon AG500. J. Wildl. Dis. 29:458-464.

Klein, R.D.. 1990. Protecting the Aquatic Environment from the Effects of Golf Courses. Community & Environmental Defense Associates, Maryland Line, MD, p. 59.

Krivak, J.A.. 1978. Best management practices to control nonpoint-source pollution from agriculture. Journal of Soil and Water Conservation 33(4): 161-166.

Lareau, J. 1995. "Golf's new course". South Carolina Wildlife Magazine. May-June. pp. 44- 47.

Love, W.R.. 1992. An Environmental Approach to Golf Course Development. American Society of Golf Course Architects©, 43 pp.

Lui, H., T.W. Fermanian, and S.G. Carmer. 1991. Expert system for planning the establishment of turfs. Agronomy Journal 83(1): 140-143.

Littrell, E.E. 1986. Mortality of American wigeon on a golf course treated with the organo-phosphate diazinon. Calif. Fish Game. 72:122-124.

Loucks, O. L. 1989. Restoration of the pulse control function of wetlands and its relationship to water quality objectives. pp. 467-478. In: J. A. Kusler and M. E. Kentula (eds.), Wetland Creation And Restoration: The Status of the Science. Island Press, Washington, DC.

Mancino, C.F., W.A. Torello, and D.J. Wehner. 1988. Denitrification losses from Kentucky bluegrass sod. Agron. J. 80: 148-153.

Markland, F.E., E.C. Roberts, and L.R. Frederick. 1969. Influence of nitrogen fertilizers on Washington creeping bentgrass, *Agrostis palustris* Huds. II. Incidence of dollar spot, *Sclerotinia homoeocarpa*, infection. Agron. J. 61: 701-705.

Meyer, F.P. and L.A. Barclay. 1990. Field Manual for the Investigation of Fish Kills. Fish and Wildlife Service, Resource Publication 177. Dept. of the Interior, Washington, D.C., 120 pp.

Miles, C.J., G. Leong, and S. Dollar. 1992. Pesticides in marine sediments associated with golf course runoff. Bull. Environ. Contam. Toxicol. 49(2): 179-185.

Mitsch, W. J. and S. E. Jorgensen. 1989. Introduction to ecological engineering. pp.3-12. In: W. J. Mitsch and S. E. Jorgensen (eds.), Ecological Engineering: An Introduction to Ecotechnology. John Wiley & Sons, New York.

Mitsch, W. J. 1993. Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution. pp. 43-70. In: R. K. Olsen (ed.), Created and Natural Wetlands for Controlling Nonpoint Source Pollution. C. K. Smoley and CRC Press, Inc. Boca Raton, FL.

Monsanto. 1983. Rodeo Herbicide: Toxicological and Environmental Properties. Bulletin No. 1, EP-005. Monsanto Agriculture Production Company, St. Louis, MO, 4 pp.

Moul, I.E. and J.E. Elliott. 1992. A survey of pesticide use and bird activity on selected golf courses in British Columbia. Technical Report Series No. 163. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia. 103 pp.

Myers, R.F., R.E. Wagner, and P.M. Halisky. 1992. Relationship between cultureal factors and nematodes on Merion Kentucky bluegrass. J. Nematol. 24(1): 205-211.

Nelson, E.B. and C.M. Craft. 1992. Suppression of dollar spot on creeping bentgrass and annual bluegrass turf with compost-amended topdressings. Plant Disease 76(9): 954-958.

Nelson, E.B., A.J. Turgeon, and J.R. Street. 1980. Thatch influence on mobility and transformation of nitrogen carriers applied to turf. Agron. J. 72: 487-492.

Novotny, V. and H. Olem. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York, 1054 pp.

Odum, H. T. 1989. Ecological engineering and self-organization. pp. 79-101. In: W. J. Mitsch and S.E. Jorgensen (eds.), Ecological Engineering: An Introduction to Ecotechnology. John Wiley & Sons, New York.

Payne, R.A.. 1987. Resource conservation: the golf course role. Golf Course Management 55(10): 50-58.

Peacock, C.H. and J.M. DiPaola. 1992. Bermudagrass response to reactive layer coated fertilizers. Agron. J. 84(6): 946-950.

Peacock, C.H., A.H. Bruneau, and S.P. Spak. 1990. Protecting a valuable resource: preservation of wetlands from a technical perspective. Golf Course Management 58(11): 6-7.

Petrovic, A.M.. 1990. The fate of nitrogenous fertilizers applied to turfgrass. Journal of Environmental Quality 19(1): 1-15.

Potter, D.A. and S.K. Braman. 1991. Ecology and management of turfgrass insects. J. Environ. Quality 36: 383-406.

Pratt, P.F.. 1985. Agriculture and Groundwater Quality. Council for Agricultural Science and Technology. CAST Report No. 103, 62 pp.

Pye, V.I., R. Patrick, and J Quarles. 1983. Groundwater Contamination in the United States. University of Pennsylvania Press, Philadelphia, 315 pp.

Rainwater, T.R., V.A. Leopold, M.J. Hooper and R.J. Kendall. 1995. Avian exposure to organophosphorus and carbamate pesticides on a coastal South Carolina golf course. Environ. Toxicol. Chem. 14(12): 2155-2162.

Randall, R.J., J.D. Butler, and T.D. Hughes. 1972. The effect of pesticides on thatch accumulation and earthworm populations in Kentucky bluegrass turf. Hortscience 7: 64-65.

Rattner, B.A. and J.C. Franson. 1984. Methyl parathion and fenvalerate toxicity in American kestrels: Acute physiological responses and effects of cold. Can. J. Physiol. Pharmacol. 62:787-792.

Roberts, D.R. and T.A. Miller. 1971. Effects of polymer formulations of Dursban and Abate on non-target organism populations April-October 1970. Entomological Spec. Study No. 31-004-71. U.S. NTIS AD-729 342. U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, MD, 24 pp.

Roberts, E.C. and B.C. Roberts. 1989. Lawn and Sports Turf Benefits. The Lawn Institute, Pleasant Hill, TN, USA, 31 pp.

Royal Canadian Golf Association. 1993. Environmental Guidelines for Canadian Golf Clubs. Oakville, Ontario, 10 pp.

Sanders, H.O. 1972. Toxicity of Some Insecticides to Four Species of Malacostracan Crustaceans. Technical Paper No. 66. Bureau of Sports Fisheries and Wildlife, Fish and Wildlife Service, U.S. Dept. of Interior, Washington D.C., 19 pp.

Schimmel, S.C., R.L. Garnas, J.M. Patrick, Jr., and J.C. Moore. 1983. Acute toxicity, biocon-centration, and persistence of AC 222,705, benthiocarb, chlorpyrifos, fenvalerate, methyl parathion, and permethrin in the estuarine environment. Journal of Agriculture and Food Chemistry 31(1): 104-113.

Siefert, R.E.. 1987. Effects of Dursban (chlorpyrifos) on aquatic organisms in enclosures in a natural pond - final report. U.S. EPA, Duluth, MN, 214 pp.

Smiley, R.W.. 1983. Compendium of Turfgrass Diseases. American Phytopathological Society, St. Paul, MN.

Smith, G.J. 1987. Pesticide use and toxicology in relation to wildlife: Organophosphorus and carbamate compounds. U.S. Fish Wildl. Serv. Publ. 170. pp. 1-6.

Snyder, G.H. and J.L. Cisar. 1992. Controlled-release potassium fertilizers for turfgrass. J. Am. Soc. Hort. Sci. 117(3): 411-414.

Starr, J.L. and H.C. DeRoo. 1981. The fate of nitrogen applied to turfgrass. Crop Sci. 21: 531-536.

Stickel, W.H.. 1974. Effects on wildlife of newer pesticides and other pollutants. Proceedings Annu. Conf. West. Assoc. Game and Fish Comm. 53:484-491.

Stone, W.B.. 1979. Poisoning of wild birds by organophosphate and carbamate pesticides. New York Fish and Game Journal 26(1): 37-48.

Stone, W.B. and H. Knoch. 1982. American brant killed on golf courses by diazinon. NY Fish Game J. 29:95-96.

Stone, W.B. and P.B. Gradoni. 1985a. Recent poisonings of wild birds by Diazinon and Carbo-furan. Northeastern Environmental Science 4(3-4): 160-165.

Stone, W.B. and P.B. Gradoni. 1985b. Wildlife mortality related to the use of the pesticide Diazinon. Northeastern Environmental Science 4(1): 30-39.

Stone, W.B. and P.B. Gradoni. 1986. Poisoning of birds by cholinesterase inhibitor pesticides. Wildlife Rehabilitation. 5:12-28.

Thirugnanam, M. and A.J. Forgash. 1977. Environmental impact of mosquito pesticides: toxicity and anticholinesterase activity of chlorpyrifos to fish in a salt marsh habitat. Archives of Environmental Contamination and Toxicology 5(4): 414-425.

Turgeon, A.J.. 1985. <u>Turfgrass Management</u> (Revised ed.). Reston Publishing Co., Reston, VA.

U.S. EPA. 1986. Pesticides in Ground Water: Background Document. EPA-WH550G. Office of Ground Water, U.S. EPA, Washington, D.C., 72 pp.

U.S. EPA. 1988a. Protecting Ground Water: Pesticides and Agricultural Practices. EPA-440/6-88-001. U.S. EPA, Office of Ground Water Protection, Washington, D.C., 53 pp.

U.S. EPA. 1988b. America's Wetlands: Our Vital Link Between Land and Water. OPA-87-016. U.S. EPA, Office of Wetlands Protection, Washington, D.C., 9 pp.

U.S. EPA. 1988c. EPA issues final order cancelling pesticide diazinon on golf courses, sod farms. Press Release, March 30. Washington, D.C.

U.S. Golf Association. 1994. Wastewater Reuse for Golf Course Irrigation. Lewis Publishers, Chelsea, MI, USA, pp. 294.

U.S. Water Resource Council. 1978. The nation's water reserves, 1975-2000. Second National Water Assessment, Vol. 1: Summary. Superintendent of Documents, Washington, D.C..

Watschke, T.L.. 1990. The environmental fate of pesticides. Golf Course Manage. 58: 18-24.

Watson, J.R., Jr., H.E. Kaerwer, and D.P. Martin. 1990. The turfgrass industry. In: TurfgrassScience. ASA-CSSA Monogr. 14 (Revised). American Society of Agronomist, Crop Science Society of America, Madison, WI, USA, 106 pp.

Weeks, M.H., M.A. Lawson, R.A. Angerhofer, C.D. Davenport and N.E. Pennington. 1977. Preliminary assessment of the acute toxicity of malathion in animals. Arch. Environ. Contam. Toxicol. 6:23-31.

White, D.H., C.A. Mitchell and E.F. Hill. 1983. Parathion alters incubation behavior of laughing gulls. Bull. Environ. Contam. Toxicol. 31:93-97.

Zinkl, J.G., J. Rathert and R.R. Hudson. 1978. Diazinon poisoning in wild Canada geese. J. Wildl. Manage. 42:406-408.